WATER BALANCE STUDY FOR A WATER-EFFICIENT LANDSCAPE SYSTEM AT THE ENVIRONMENTAL CENTER OF THE ROCKIES WATER YEAR 1999

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Rear Planter & Catch Pond— Photo ©Len Wright

INTRODUCTION

In the spring of 1999, The Environmental Center of the Rockies (Environmental Center), a two-story office facility located in Boulder, Colorado, was retrofitted with a water-efficient landscape system. The system designed by William Wenk of Wenk Associates, combines water efficient plants with routing of storm runoff into detention basins to increase infiltration and decrease stormwater discharge. The goals of the landscape retrofit are to: (1) conserve water and energy use for the facility;

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(2) decrease stormwater runoff discharged to storm sewers; and (3) decrease transport of water-born pollutants from the facility. Funding for the project was contributed, in part, by The National Geographic Society in recognition of the site for its use of technology to conserve natural resources. Wright Water Engineers, Inc. (WWE) was contracted by the City of Boulder's Water Conservation Department to collect hydrologic data and estimate the water-efficiency of the system by computing a water balance for the facility.

SCOPE

This report presents the results of the water-balance for the Environmental Center for Water Year 1999 (October 1998 - September 1999). Adequate resources were made available to collect data for: (1) precipitation; (2) runoff; and (3) air temperature to estimate the magnitude of the water-balance components. The water balance equation for this study is:

$$\text{Precipitation} + \text{Irrigation} = \text{Runoff} + \text{Evapotranspiration} + \text{Infiltration} + \text{Biomass}$$

(Equation 1)

For this study, free water surface evaporation is assumed to be negligible, and it is accounted for in the evapotranspiration term. This is a reasonable assumption because there is very little opportunity to accumulate freestanding water (e.g., ponding) for evaporation.

An estimation of the landscaping irrigation requirements, based on calculated evapotranspiration, is provided herein. Recommendations for continued monitoring are also provided. As previous evaluation of the Environmental Center's landscape water efficiency concluded that a retrofit of the previous landscape would reduce water demand, but not eliminate the need for irrigation (Roesner 1998). Comparison of Roesner's results with the monitoring data were not done because the new landscape system is not yet mature enough for a meaningful comparison.

STUDY AREA

The Environmental Center facility is located in a high traffic area on the corner of Baseline Street and Broadway Boulevard in Boulder, Colorado. Prior to the landscaping retrofit, the site was predominantly an irrigated turf grass landscape. The new landscaping system uses water-efficient grasses, shrubs and flowering plants that give the site a more natural appeal.

The study area is in a semi-arid climate with an annual average precipitation depth of about 18.6 inches (NCDC 1998). The monthly average temperature ranges from 0.3° C in winter to 22.8° C in summer, based on the previous 30 years of data collected at the National Climatic Data Center's Boulder, Colorado station number 50848 (NDC 1998).

Estimated drainage areas for the site are shown in Table 1. The drainage areas were estimated from an AutoCad™ plan of the landscape design drawing provided by Wenk Associates. Note that this drawing does not accurately reflect as-built conditions. WWE added field measurements and a level survey to the plan, to make it adequate for analysis herein. The southern portion of the office building and west parking area drain to an alley that parallels the south wall of the building. This area, which does not drain to the landscaping system, is not included in the study area for this analysis.

Table 1: Estimated Drainage Areas for The Environmental Center, Boulder, Colorado

Area Description	Area (Ft.^{2})
Roof Draining to Landscaping	4,179
Parking Draining to Landscaping	2,446
Parking Draining to Median	1,406
Amphitheater	402
East Court Yard	1,527
Atrium	402
Irrigated Landscaping	7,294
Total	**17,656**

A map of the study area is shown in **(Figure 1)**. Arrows in Figure 1 show the direction overland runoff flow would take. The location of the site monitoring stations are also shown in Figure 1.

HYDROLOGIC MONITORING

Precipitation, air temperature and runoff were measured continuously for Water Year 1999. The monitoring instruments are still operational. Data collection is being continued by Colorado University as part of an U.S. Environmental Protection Agency (EPA)-funded research project.

Precipitation

Precipitation was measured with a Global Water continuously recording, tipping bucket rain gage. The precipitation gage measures rain, when it occurs, at 5-minute time increments. On days with no precipitation, the gage records a single record of zero inches. The precipitation gage is located on the west side of the Environmental Center's roof **(Figure 1)**. The roof location provides protection from vandalism, and keeps the gage out of the rain shadows for collection of representative data. There was no missing data in the precipitation record for Water year 1999. The hietograph for Water Year 1999 is shown in **Figure 2**.
The total measured precipitation was 21.73 inches.

Runoff

Runoff was measured at two stations located upstream and downstream of the landscaping systems detention pond on the east side of the building. These stations were located to measure the inflow to the detention pond and the discharge of runoff from the landscaping system **(Figure 1)**. The runoff monitoring stations are equipped with Global Water WL-14™ data logger/pressure transducer units. These instruments measure and log stage (water level) data continuously on 10 to 15 minute intervals. At both stations, the stage was measured upstream from rectangular, contracted broad-crested weirs made from sandstone blocks. The weirs are components of the landscaping that also provide a means of converting stage to discharge (i.e., measured stage in feet to discharge in cubic feet per second). The pressure transducers are attached to staff gages, which were used to calibrate the logged stage data to observed stage readings. The staff gages were read during selected storm events by Leslie Kaas (Land and Water Fund of the Rockies) and Len Wright (Colorado University CU).

The upstream location, LWF#1, has the most complete record of the two runoff monitoring stations **(Figure 3)**. The record for LWF#1 shows that water accumulated behind the weir on several occasions. However, water flowed over the weir at LWF #1 only twice on August 4 and 5, 1999 **(Figure 4)**. Data are missing for June 16 - July 16 and September 15 - September 30 due to dead batteries and full logger memory, respectively.

Station LWF#2 was not measuring stage properly for a large portion of the Water Year, and the manufacturer replaced the instrument. After the instrument was replaced, the battery on LWF#2 died two days before large storms dropped more than 3 inches of precipitation on the site in less than two days between August 4 and 5, 1999. However, CU engineering student, Len Wright, observed flow at LWF#1 on August 4, which accumulated in the detention pond but reportedly did not discharge over the weir at LWF#2. WWE staff member, Jonathan Jones, P.E., observed water flowing over the weir at LWF#2 on the evening of August 5. This observation is consistent with the data from LWF#1, which measured a total yield of 101 cubic feet on August 4 and 1,237 cubic feet on August 5. The detention pond holds an estimated 450 cubic feet, based on a WWE survey of the pond topography. Therefore, about 900 cubic feet of runoff were discharged from the site on August 5 (i.e., 1,237 cf (on August 5) - 450 cf (pond capacity) +101 cf (discharged to the pond on August 4). The monitoring data indicate that this is the only water lost from the site as runoff in Water Year 1999. A hydrograph for LWF#2, which shows no flow while the instrument was recording, is shown in **Figure 5**.

Planter boxes, located on the west side of the building, collect runoff from the parking lost and the roof of the building. These planter boxes could potentially fill with runoff water to a point where they could overflow and thus take on no more water. Such overflows would affect the water efficiency of the landscaping system. Therefore, crest stage indicators (CSIs) were installed on the outlets of the planter boxes **(Figure 1)** to indicate when water levels in the planter boxes are high enough for overflow to occur. The CSIs are made from galvanized pipes with wooden staffs inside connected to a pulverized cork reservoir. When water enters the CSIs through holes in the bottom cap, the cork floats on the water surface and sticks to the wooden staff at the maximum water level (i.e., the crest stage). The water levels are read and recorded after the water recedes. No

CSIs showed overflow from the planter boxes in Water Year 1999.

Air Temperature

Air temperature data were collected on four-hour increments at six monitoring locations labeled as AIR1 - AIR6 **(Figure 1)**. The temperature data were collected with HOBO™ temperature loggers manufactured by Onset Computer Corporation. The battery operated temperature loggers were mounted inside plastic containers on landscaping poles at an elevation of 5 feet above the land surface. The loggers were placed in various locations around the Environmental Center property to represent different micro-climates (e.g., shade, parking lot, sunny areas, etc.).

Stations AIR1 and AIR6 were vandalized on October 31, 1998 (Halloween). The logger from station AIR3 was moved to the AIR6 location and a new, waterproof HOBO™ logger was purchased and installed at the AIR3 location. The AIR1 logger was repaired, but it was later moved to the AIR2 station because AIR2 was stolen. The AIR1 station was not replaced. Some data were lost due to dead batteries and software problems. However, five stations provided very consistent data during most of the growing season for estimation of evapotranspiration. Five stations (AIR2 - Air6) are still operational.

The air temperature data are shown in **Figure 6**, and the data are summarized by month in Table 2. These data were used to calculate the evapotranspiration (i.e., water use and evaporation by plants) for the landscaping.

Table 2: Water Year 1999 Monthly Average Air Temperature for the
Environmental Center of the Rockies Boulder, Colorado

Month	Average Temp. (ºC)	Number of Stations Reporting
10	11.2	4
11	7.0	4
12	4.9	1
1	No Data	0
2	5.5	5
3	6.9	5
4	6.6	4
5	13.5	4
6	17.5	4
7	23.0	4
8	21.2	0
9	12.6	4

DATA ANALYSIS

Evapotranspiration, runoff and infiltration account for almost all of the components of the Environmental Center water balance for Water Year 1999. Negligible ponding of water occurs for evaporation to occur. Therefore, the evaporation component is likely some small percentage of the calculated amount of infiltration or evapotranspiration. **(Figure 7)** shows the relative proportions of precipitation that fell on the entire site (30,500 cubic feet) and irrigation water applied to the landscaping (about 50,000 cubic feet), infiltrated (64,600 cubic feet), or lost from the system as runoff (900 cubic feet).

Evapotranspiration

Evapotranspiration was computed by the Soil Conservation Service's TR-21, Blaney-Criddle method for a bluegrass crop (FAO 1977; USDA/SCS 1970 and 1975). Bluegrass is less water efficient than the plants in the new landscaping system, but the plants have not yet developed deep roots, litter, or basal cover on the ground in their first year of growth. Therefore, the bluegrass crop was selected for estimation of evapotranspiration during the first growing season.

The evapotranspiration of the irrigated landscaping area was estimated to be 24.8 inches in Water Year 1999. The 30-year average evapotranspiration, based on a 30-year record of temperature and precipitation from the NCDC Boulder, Colorado monitoring data (NCDC 1998), is 26.9 inches. Evapotranspiration accounted for about 19% of the water applied to the entire site.

Based on the Blaney-Criddle method, the landscaping was over-watered throughout most of the growing season. **(Figure 8)** shows that the applied water to the landscaping far exceeded the plants' water demand. The annual average precipitation for Boulder, Colorado is 18.6 inches (NCDC 1999). Therefore, Water Year 1999 had slightly above average precipitation (21.73 inches). Even so, the landscaping would have been over-watered in average precipitation conditions. It is a common practice to supply newly planted vegetation with ample water, but curtailing irrigation in the second year will help to more deeply root the plants and thus make them more drought tolerant.

Thus, bluegrass was used as a crop for evapotranspiration calculation to represent water use in the first growing season for the landscaping plants. In subsequent studies, a crop that more closely resembles the landscaping vegetation should be used to account for increased water efficiency in subsequent growing seasons.

Runoff

As mentioned earlier, very little runoff left the landscaping system. About 900 cubic feet of water were discharged from the landscaping system on August 5, 1999. **(Figure 7)** shows that runoff accounted for about 1 percent of the total water applied to the site in Water Year 1999.

Infiltration

Infiltration was not directly measured in any way, but it was estimated by subtracting the quantities of water accounted for by evapotranspiration and runoff from the total amount of water applied to the site. In Water Year 1999, about 80 percent of the applied water was lost to the subsurface by infiltration. This result is consistent with the design of the system, which is intended to promote infiltration and limit runoff. Continuing investigation of the water efficiency of the landscaping by CU includes monitoring of shallow groundwater levels and soil moisture to more accurately estimate infiltration characteristics. The infiltration characteristics of the landscaping will likely change as the vegetation matures and generates basal and litter cover, root mass and more plants. These processes should increase water detention on the surface, which in turn might increase runoff slightly.

CONCLUSIONS

1. The monitoring data collected in Water Year 1999 at the Environmental Center indicate that the retrofitted landscaping system performed as designed by infiltrating between 70 and 80 percent of the water applied to the site as precipitation and irrigation water. Only 1 percent of the applied water left the system as runoff. Approximately 19 percent of the applied water was evapotranspired by plants. An estimated 1 to 10 percent of the applied water was incorporated into the plant biomass, but this quantity is not estimated from any collected data.

2. Estimation of the evapotranspiration for Water Year 1999 indicates that the landscaping system was over-watered. Watering could be cut back in the next growing season. This will conserve water and help the plants become more deeply rooted and drought tolerant.

3. The CU Engineering Department is expanding the monitoring of the site as part of an EPA grant administered by the City of Boulder to obtain more detailed knowledge of the long-term functionality of water-efficient landscape systems. The CU study will include monitoring shallow groundwater levels and soil moisture. CU will also continue to collect precipitation, air temperature and runoff data using the instruments installed by WWE in Water Year 1999. Pan evaporation data and an estimation of the water incorporated into the live biomass in the system would be useful.

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